UNIVERSITY OF CAMBRIDGE

Reduced-order Jet Noise Modelling for Chevrons

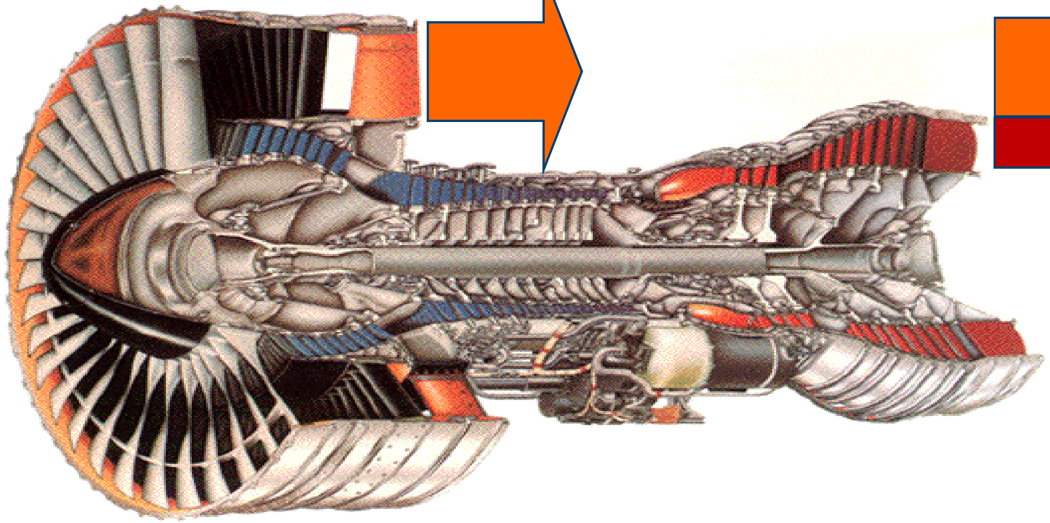
Karthik Depuru

PhD in Engineering
Acoustics Research Laboratory
E-mail: nkd25@cam.ac.uk

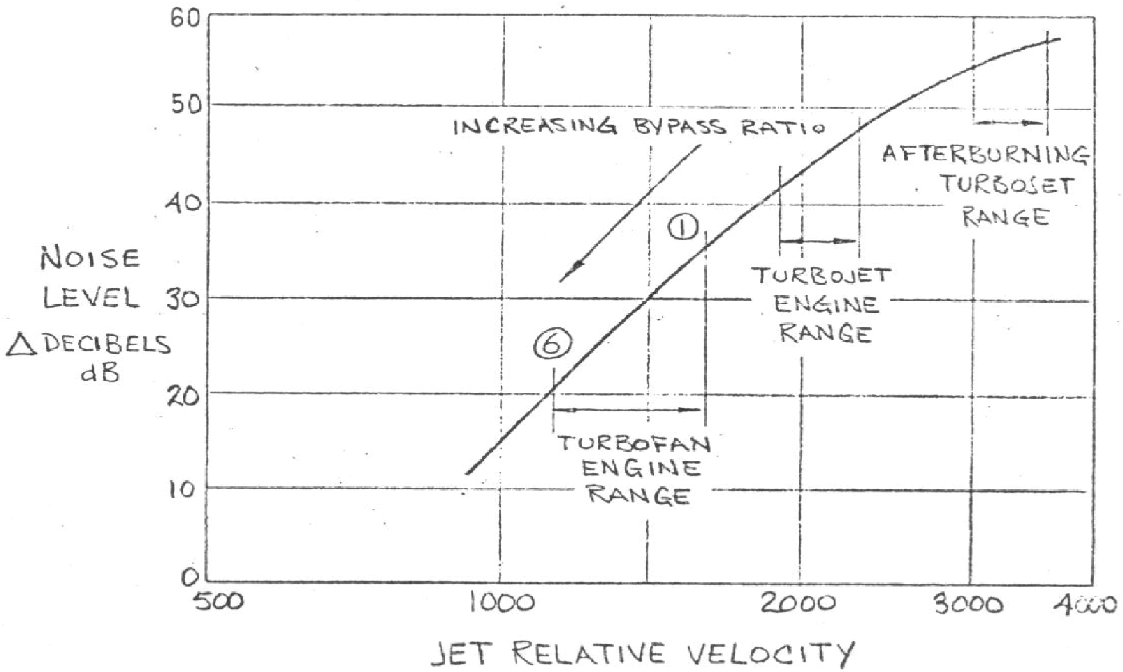
Supervisor: Professor Dame Ann Dowling

Department of Engineering **St John’s College**

Jet Noise

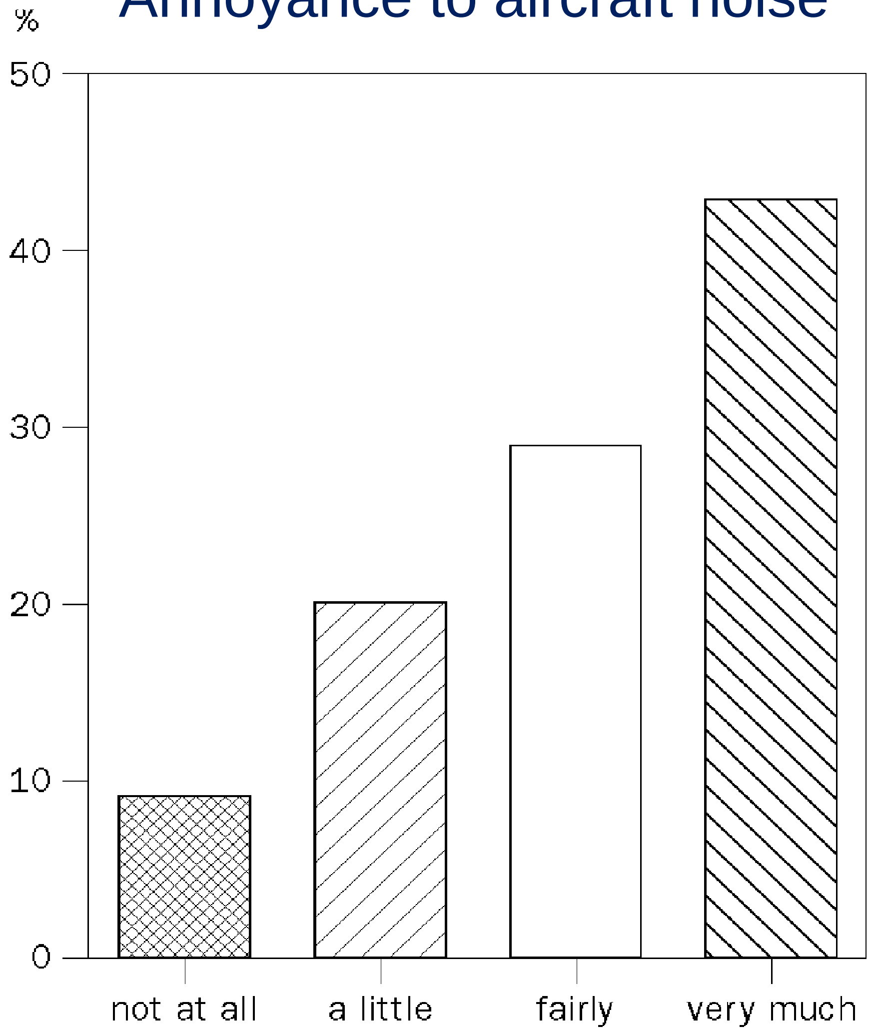


Large velocity gradient
Large shear tends to be noisy
Acoustic noise level scales as U^6_{jet}-U^8_{jet}

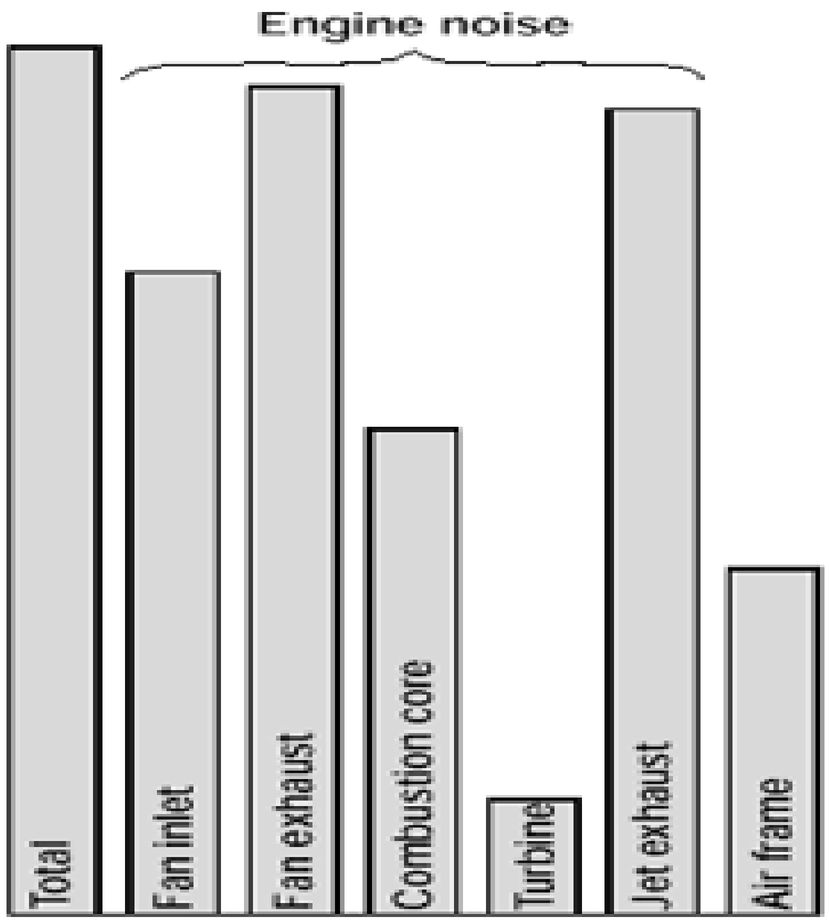


Motivation

Annoyance to aircraft noise



Components of aircraft noise



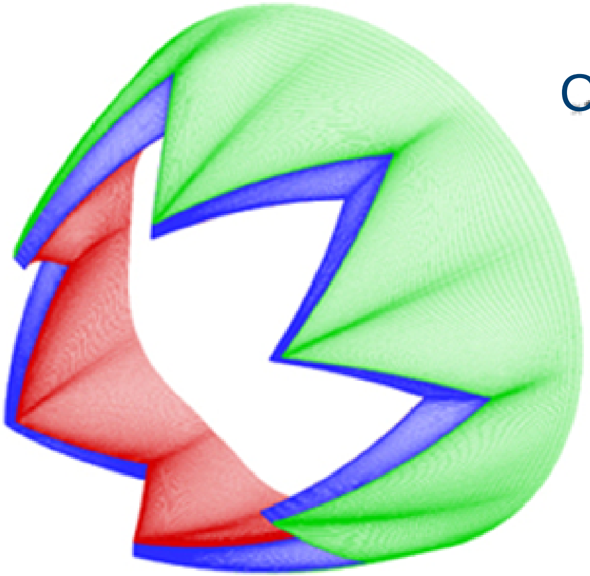
Objective

- To develop a methodology to identify the noise sources of chevrons using a reduced-order turbulence model (RANS) with higher accuracy.

Significance

The methodology will enable accurate prediction of jet acoustic field by using RANS data (less expensive) instead of LES data (expensive). It will significantly reduce computational cost involved in jet noise prediction.

Geometric and Flow Details



Courtesy: NASA

Geometric Details:

- Nozzle ID - SMC006
- # of chevrons = 6
- Effective diameter = 50.8 mm
- Bend angle = 18.2 degrees
- Penetration = 3.525 mm
- Tip-to-tip distance = 42.9 mm

Flow Details:

- Reynolds number = 1.03×10^6
- Mach number = 0.9

Correlations

4th order space time correlation is given by,

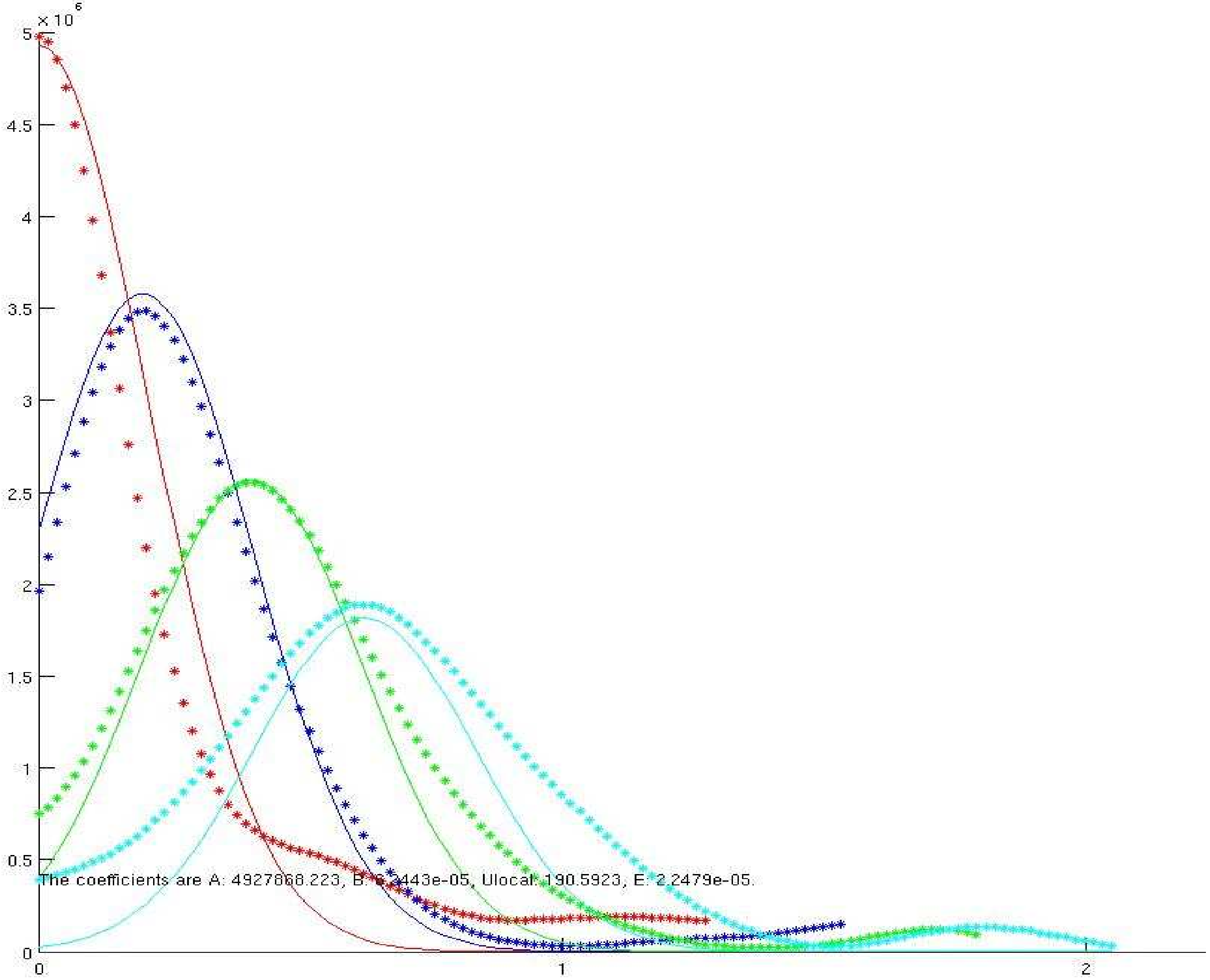
$$R_{ij,kl}(\underline{x},\underline{\Delta x},\Delta\tau) = \overline{u_i'(\underline{x},\tau).u_j'(\underline{x},\tau).u_k'(\underline{x}+\underline{\Delta x},\tau+\Delta\tau).u_l'(\underline{x}+\underline{\Delta x},\tau+\Delta\tau)}$$
$$-\overline{u_i'(\underline{x},\tau).u_j'(\underline{x},\tau)} * \overline{u_k'(\underline{x}+\underline{\Delta x},\tau+\Delta\tau).u_l'(\underline{x}+\underline{\Delta x},\tau+\Delta\tau)}$$

Gaussian approximation:

$$R_{11,11}(\underline{x},\underline{\Delta},\tau) = \underbrace{A * e^{\frac{-\Delta_1}{\overline{u}B}}}_{DecayEnvelope} * \underbrace{e^{\left[-\ln 2\frac{(-\Delta_1-\overline{u}\tau)^2+\left(\Delta_2^2+\Delta_3^2\right)}{E}\right]}}_{GaussianForm}$$

Axial Correlations

$R_{11,11}$



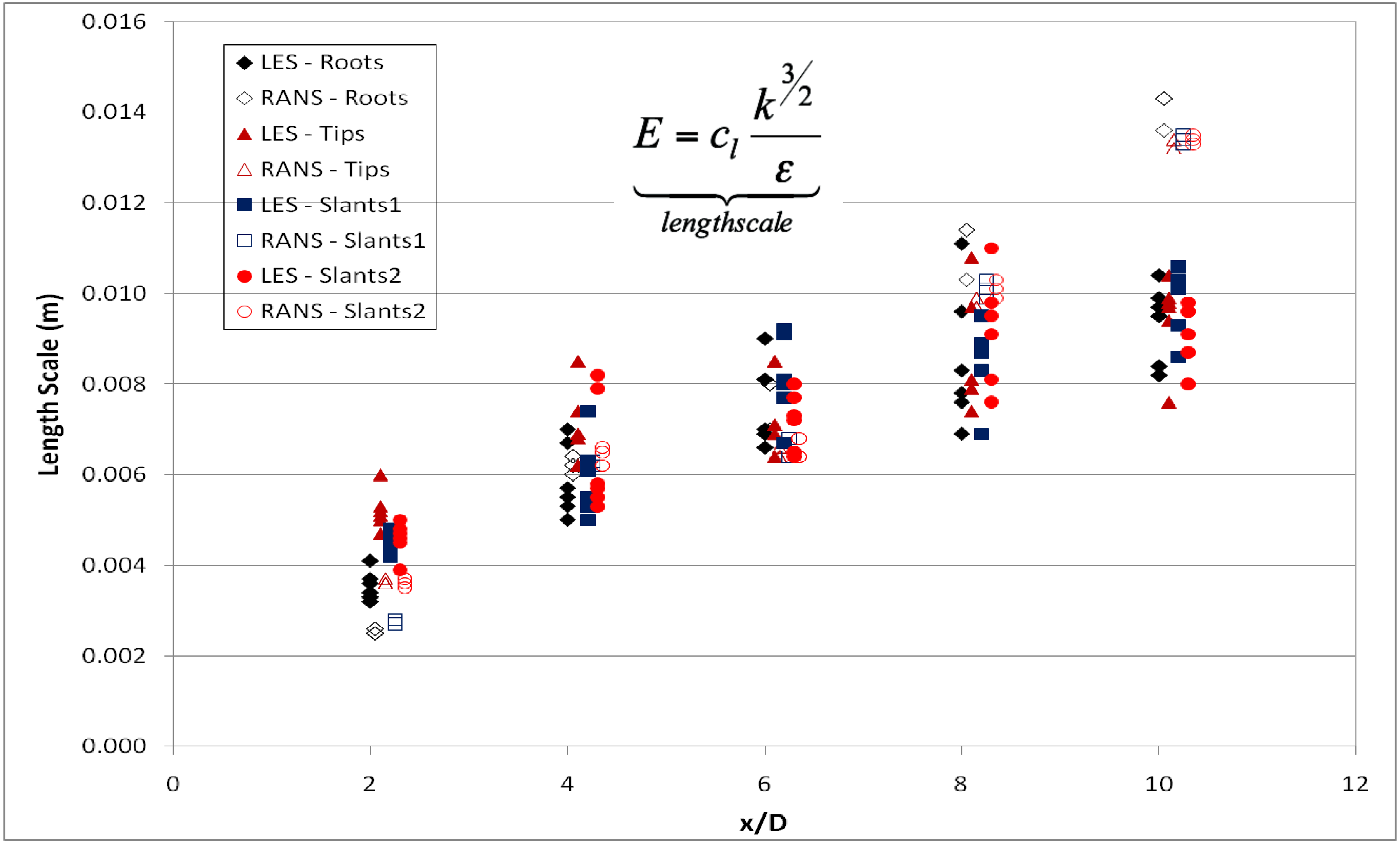
Time

Relationship among Length Scales

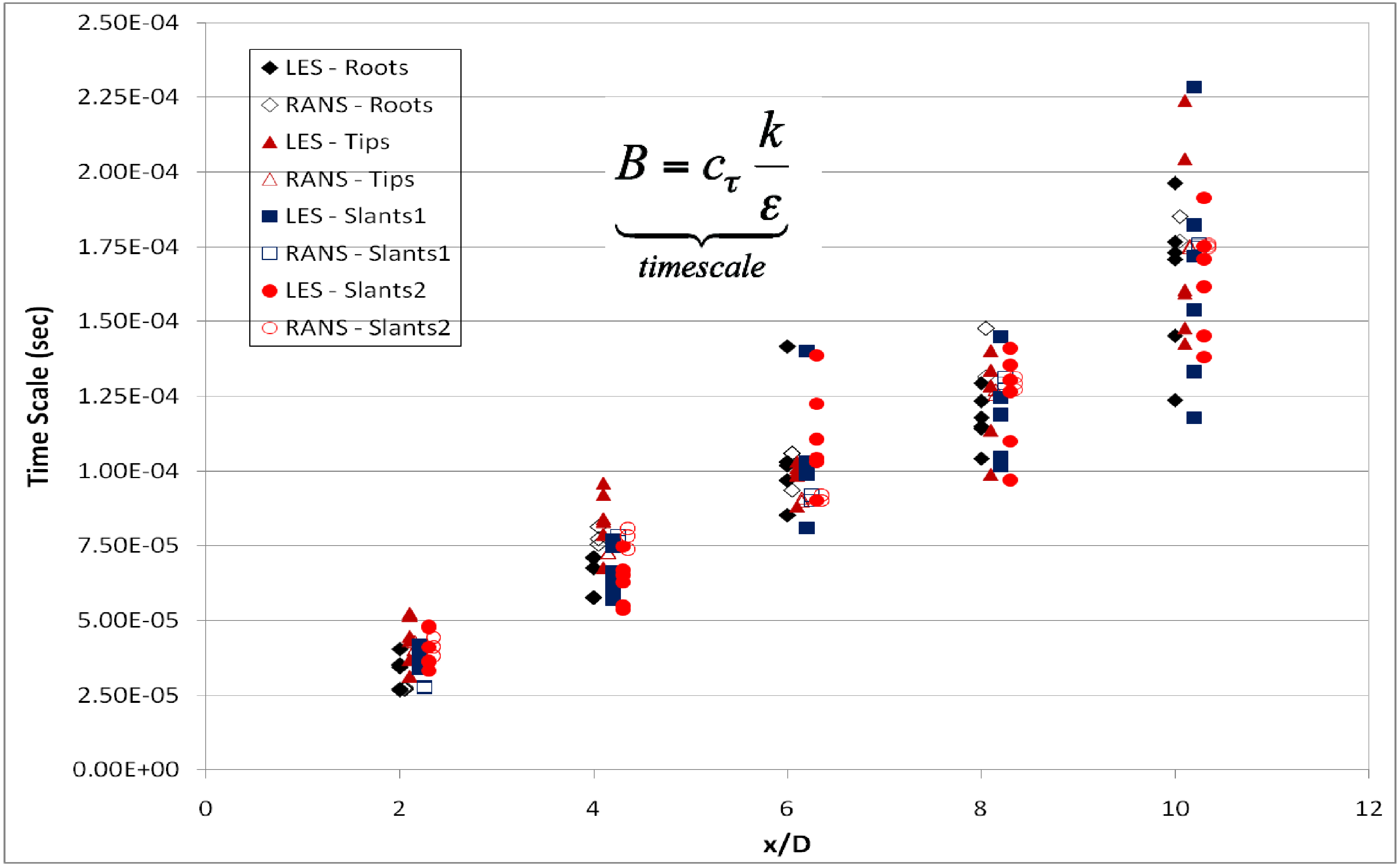
Length scale (m)					
x/D	**Axial**	**Radial**	**Azimuthal**	**Radial/Axial**	**Azimuthal/Axial**
2	0.004067	0.001170	0.001583	0.29	0.39
4	0.005554	0.001841	0.001970	0.33	0.35
8	0.008400	0.002941	0.002402	0.35	0.29
10	0.009545	0.003292	0.002863	0.34	0.30

$L_{axial} \sim 3\ L_{radial}$ and $3\ L_{azimuthal}$

Length Scale (C_l = 0.3)

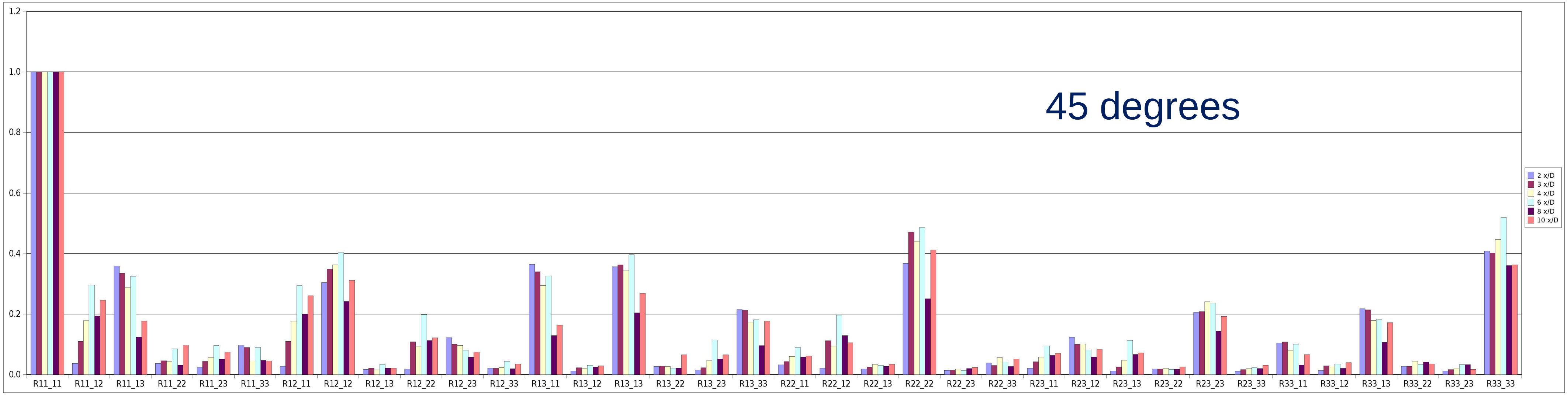


Time Scale ($C_\tau = 0.16$)

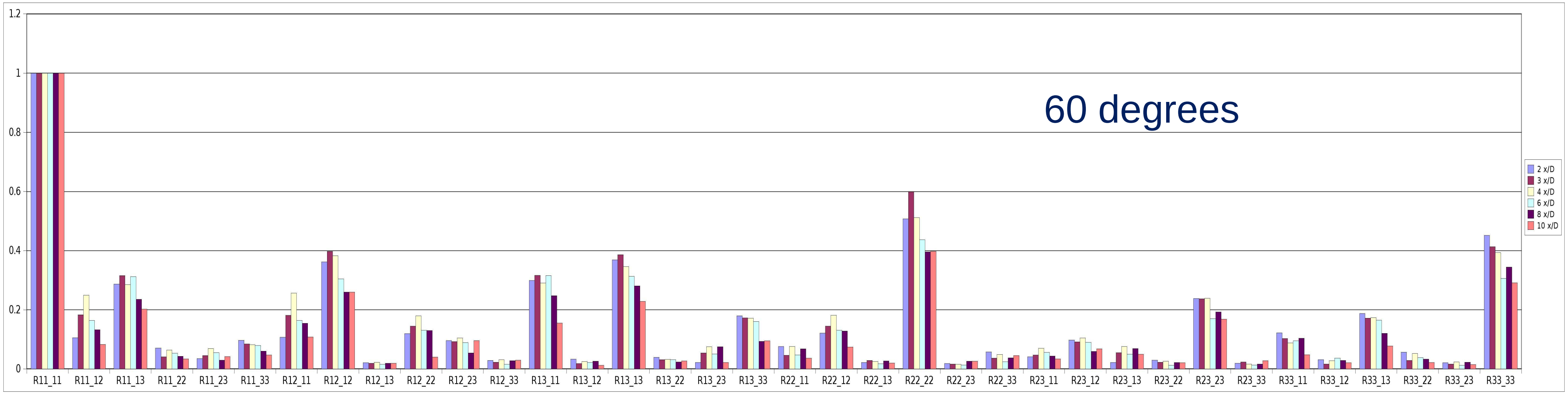


Directivity

45 Degrees



60 Degrees



Comparison of $R_{22,22}$ & $R_{33,33}$ with $R_{11,11}$

Tips		
x/D	**Rel. R22,22**	**Rel. R33,33**
2	0.47	0.49
4	0.43	0.43
6	0.42	0.36
8	0.29	0.30
10	0.32	0.30

Roots		
x/D	**Rel. R22,22**	**Rel. R33,33**
2	0.56	0.56
4	0.49	0.59
6	0.45	0.46
8	0.33	0.36
10	0.34	0.34

- For x/D ≤ 2, $R_{11,11}$ is ~2 times the $R_{22,22}$ and $R_{33,33}$
- For x/D ≥ 8, $R_{11,11}$ is ~3 times the $R_{22,22}$ and $R_{33,33}$

Conclusion

1. Gaussian form fits well the axial, radial and azimuthal correlations
2. Axial length scale is ~3 times the radial and azimuthal length scales
3. Constants of Proportionality are evaluated: $C_l = 0.30$; $C_T = 0.16$
4. Relationship exists among tips, roots and slants till $x/D = 6$; $L_{tip} > L_{slant} > L_{root}$
5. Chevron behaves as a round jet beyond $x/D = 6$
6. $R_{11,11}$ is the predominant noise source; other major noise sources are: $R_{22,22}$ and $R_{33,33}$; $R_{12,12}$, $R_{13,13}$ and $R_{23,23}$
7. For $x/D \geq 8$, $R_{11,11}$ is approximately 3 times the $R_{22,22}$ and $R_{33,33}$

With the proportionality constants, RANS scales can describe the noise sources as accurately as LES scales. This is a huge cost saving!